

CARBON SEQUESTERED, CARBON DISPLACED AND THE KYOTO CONTEXT

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ABSTRACT

The integrated system that embraces forest management, forest **products, and** land-use change impacts the global carbon cycle - and hence the net emission of the greenhouse gas carbon dioxide - in four fundamental ways. Carbon is stored in living and dead biomass, carbon is stored in wood products and landfills, forest products substitute in the market place for products made **from** other materials, and forest harvests can be used wholly or partially to displace fossil fuels in the energy sector. Implementation of the Kyoto **Protocol** to the United Nations Framework Convention on Climate Change would result in the creation of international markets for carbon dioxide emissions **credits**, but the current Kyoto text does not treat all carbon identically. We have developed a carbon accounting model, GORCAM, to examine a variety of scenarios for land management and the production of **forest products**. In this paper we explore, for **two** simple scenarios of forest management, the carbon flows that occur and how these might be accounted for under the Kyoto text. **The** Kyoto protocol **raises** questions about what activities can result in emissions credits, which carbon reservoirs will be **counted**, who will receive the credits, and how much credit will be available? The Kyoto Protocol would **sometimes** give credits for carbon sequestered, but it would always give credits when fossil-fuel carbon dioxide emissions are displaced.

If a forest grows on land not previously in forest, carbon will accumulate in the growing biomass and there will be a decreased accumulation of the **greenhouse** gas carbon dioxide in the Earth's atmosphere. **This** is a common vision of how afforestation can be used to mitigate the accumulation of carbon dioxide in the atmosphere and the potential importance of carbon sinks is acknowledged in The Kyoto protocol to **the** United Nations Framework Convention on Climate Change [1]. If **ratified**, the Kyoto Protocol would permit the country responsible for **afforestation** to use the accumulating carbon as a credit against its commitments to reduce greenhouse gas emissions - if the afforestation **occurred** since 1990 and the change in carbon stocks is **reported** in a "transparent and **verifiable** manner". Although the Kyoto Protocol is not explicit, we expect that this offset credit should include all carbon **stocks in** the forest, including the carbon in the forest soil.

In Figure 1 we use the **output from** our carbon accounting model to illustrate the accumulating carbon credits for a simple afforestation scenario. The **figure** shows that **over** time carbon will accumulate in the forest stand, including in the forest soil and forest litter, but that eventually trees **approach** maturity and the stand is unable to **accumulate** additional carbon. It approaches a steady-state carbon stock.

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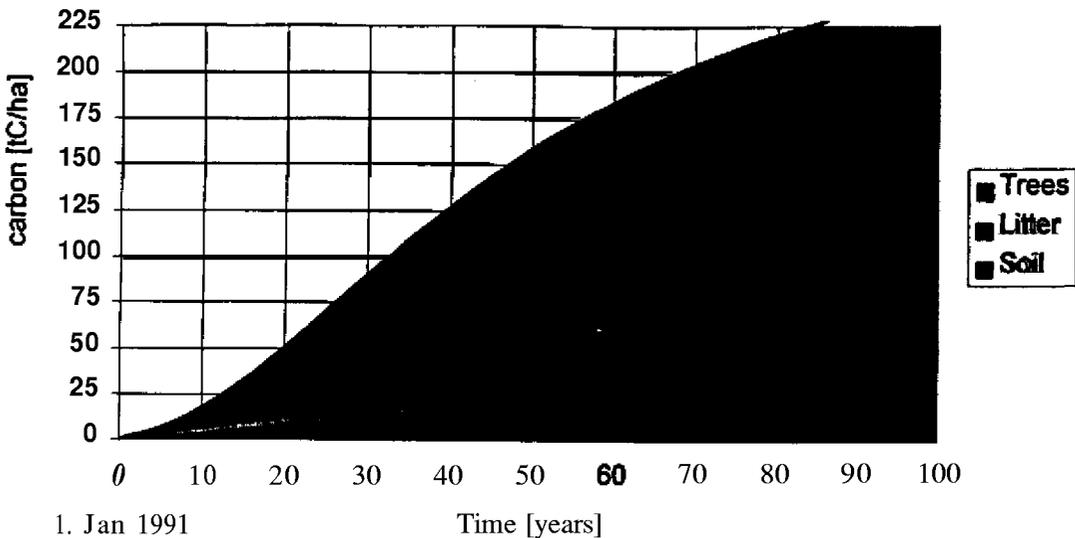


Figure 1: Cumulative carbon-stock changes for an afforestation scenario.

There are, of course, many land-use and forest management practices that could impact the net emission of carbon dioxide to the atmosphere. Our focus here is on analyzing these impacts and on the way in which changes in carbon stocks will be measured, monitored, and credited in international efforts to “prevent dangerous anthropogenic interference with the climate system” [2]. The model GORCAM (Graz/Oak Ridge Carbon Accounting Model) has been developed to try to examine the full system that is impacted by forest management decisions and to illustrate the effect that these decisions have on net carbon dioxide emissions. Protection of a growing forest stand, for example, can not only prevent the emission of its carbon stocks to the atmosphere, but can permit continuing accumulation of carbon from the atmosphere until the stand approaches maturity. If the same stand is harvested to produce a conventional mix of forest products, there will be an initial loss of carbon in the forest, but there will be an increase in carbon in forest products and an increase in the substitution of forest products and bioenergy for other products and other sources of energy. (This is under the assumption that increased harvest is coupled with an increased demand for wood products).

In Figure 2, output from GORCAM illustrates the net impact on atmospheric CO₂ if the forest stand from Figure 1 is harvested after 40 years and the harvest is used for a conventional mix of forest products. The numeric details of Figure 2 depend on the exact values for many input parameters in the model so the diagram presented here should be taken to illustrate the nature of the flows rather than to demonstrate their values. Nonetheless, the figure shows that when the forest is harvested carbon is sequestered in harvested materials (including, eventually, landfills) and that harvested materials substitute for other products that are generally more energy intensive to produce. Details of GORCAM can be found in Schlamadinger and Marland [3] and a sensitivity analysis of the importance of some of the principal model parameters is in Marland and Schlamadinger [4]. Whereas the carbon in the protected forest stand of Figure 1 can be expected to approach some steady state value over time, the carbon displacement of Figure 2 can be expected to continue to increase over time. Note that the expected carbon sequestration after 50 years amounts to 128 tC / ha.

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If a forest grows on land not previously in forest, carbon will **accumulate** in the growing biomass and there will be a decreased accumulation of the greenhouse gas carbon dioxide in the Earth's atmosphere. This is a common vision of how afforestation can be used to mitigate the accumulation of carbon dioxide in the atmosphere and the potential importance of carbon **sinks** is acknowledged in The Kyoto Protocol to the United Nations Framework Convention on **Climate** Change [1]. If ratified, the Kyoto Protocol would permit the country responsible for afforestation to use the accumulating carbon as a credit against its commitments to reduce greenhouse gas emissions - if the **afforestation** occurred since 1990 and the change in carbon stocks is reported in a "transparent and verifiable manner". Although the Kyoto Protocol is not explicit, we expect that this offset credit should include all carbon **stocks** **in** the forest, including the carbon in the forest soil.

In Figure 1 we use the output from our carbon accounting model to illustrate the accumulating carbon credits for a simple afforestation scenario. **The figure** shows that over time carbon will accumulate in the forest stand, including in the forest soil and forest litter, but that **eventually** trees approach **maturity** and the stand is unable to accumulate additional carbon. It approaches a steady-state carbon stock.

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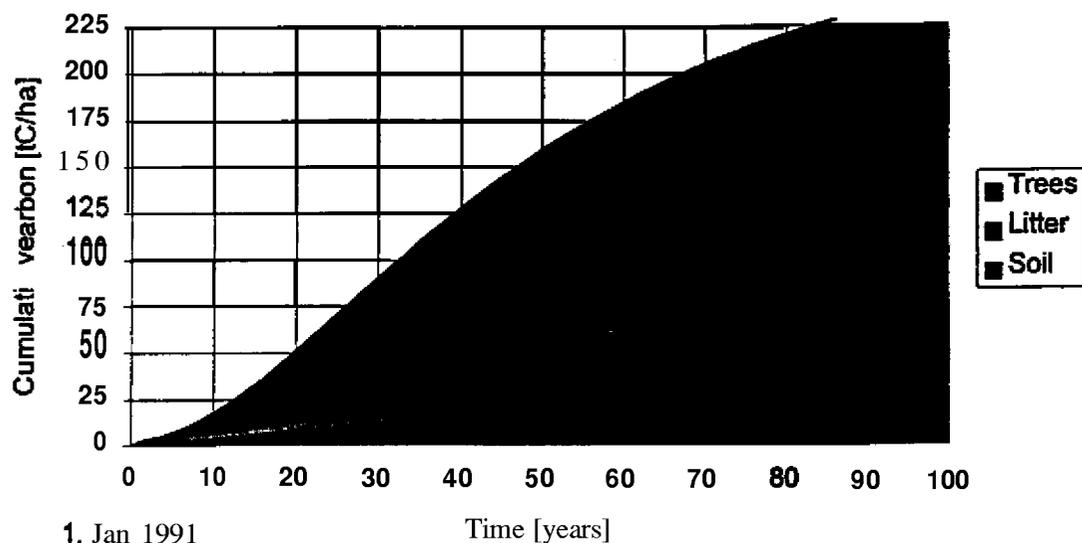


Figure I: Cumulative carbon-stock changes for an **afforestation** scenario.

There are, of course, many land-use and forest management **practices that could** impact the **net** emission of carbon dioxide to the atmosphere. Our focus here is on **analyzing** these impacts and on the way **in** which changes in carbon stocks **will** be measured, monitored, and **credited** in **international** efforts to “prevent dangerous **anthropogenic interference** with the **climate** system” [2]. The model GORCAM (**Graz/Oak Ridge Carbon Accounting Model**) has been developed to try to examine the **full** system that is impacted by forest management decisions and to **illustrate** the **effect that these** decisions have on net carbon dioxide emissions. Protection of a growing forest stand, for example, can not **only** prevent the emission of **its** carbon stocks to the atmosphere, but can permit continuing **accumulation** of carbon **from the** atmosphere until the stand approaches maturity. If the same stand is harvested to produce a conventional mix of forest products, there will be an initial loss of **carbon** in the forest, but there will be an increase in carbon in forest products and an increase in the **substitution** of forest products and **bioenergy** for other products and other sources of energy. (This is under the assumption that **increased** harvest is coupled with an increased demand for wood products).

In Figure 2, **output from** GORCAM **illustrates** the net **impact** on atmospheric **CO₂** if the **forest** stand from Figure 1 is harvested after 40 years and the harvest is used for a **conventional** mix of forest products. The numeric details of Figure 2 depend on the exact **values** for many input parameters **in** the model so the diagram presented here should be taken to **illustrate** the **nature** of the flows rather than to demonstrate their values. Nonetheless, the **figure** shows that when the forest is harvested carbon is sequestered **in** harvested materials (**including**, eventually, landfills) and that harvested materials substitute for other products that are generally more energy intensive to produce. Details of GORCAM can be found in **Schlamadinger** and **Marland** [3] and a sensitivity analysis of the importance of some of the principal model parameters is in **Marland** and **Schlamadinger** [4]. Whereas the carbon **in** the protected forest stand of Figure 1 can be expected to approach some steady state **value** over time, the carbon displacement of Figure 2 can be expected to continue to increase over **time**. Note that the expected carbon sequestration **after** 50 years amounts to 128 tC / ha.

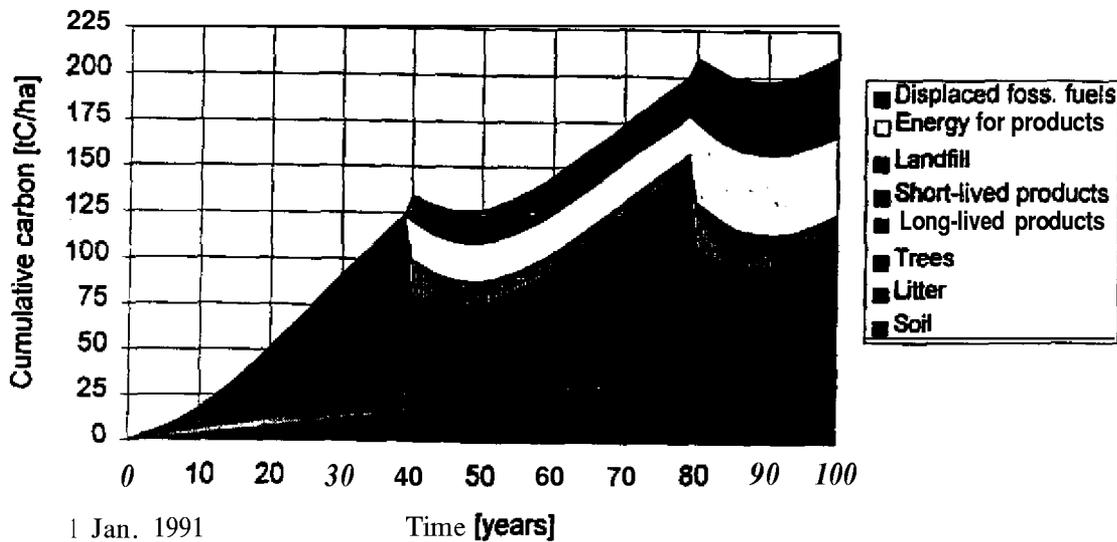


Figure 2: **Cumulative** carbon-stock changes for a **scenario involving afforestation and harvest**. These are net changes in that, for example, **the diagram** shows savings in **fossil fuel emissions** with respect to an alternate scenario that uses fossil **fuels** and alternative, more energy-intensive **products** to provide the same services.

On a global scale, the relative merits of forest **protection** versus forest harvest (in terms of net carbon dioxide emissions to the atmosphere) will depend **importantly** on the status of **the forest** at the beginning of the accounting, the forest productivity, the **efficiency** with which forest **products are** produced and used, and on our perception of how time **and uncertainty** should be treated [4].

These two **figures** display **the principal** impacts that the respective scenarios would have on the global carbon budget, but they raise **challenging** questions in the context of the Kyoto Protocol. **The Kyoto Protocol specifically** establishes in **Article 3.3** that credits or debits can be obtained for **afforestation, reforestation, and deforestation** since 1990. That is, the carbon **accumulated** in the scenario of Figure 1 could be used to meet national commitments whereas there is continuing uncertainty about how the carbon stock changes represented in Figure 2 might be counted. (It is, for example, not yet established how harvesting of forests **planted** since 1990 **should** be accounted for. If a forest stand is planted after 1990 and subsequently harvested during a commitment period, **should** the stock change toward a lower level show up in the accounting?).

Two points should be made about Figure 1. **First**, the Kyoto Protocol is not absolutely clear which stocks are to be included as part of the forest. **The carbon in** above ground biomass is surely to be counted. Our feeling is that the carbon in forest **soils** and litter is equally a part of the forest but there is continuing discussion about whether this will **be** generally accepted. **The** decision will likely hinge on the requirement that increases in **carbon** stocks be measured in a reliable and **verifiable** manner. Second, the Kyoto Protocol provides that developed countries (listed **in** its Annex B) can pursue activities in non-Annex B countries and use the emissions reduction credits in the accounts of **the Annex B country**. This text in Article 12 does **not clearly** establish whether or not carbon sinks in **non-Annex B** countries can be used, similarly to the emissions reductions, in the accounts of the Annex B partner.

The issues raised concern both what activities can produce carbon credits for increasing carbon storage in sinks **and** what carbon pools will be counted. Whereas Article 3.3 **of the Kyoto** protocol limits credits to afforestation, reforestation, and **deforestation**, Article 3.4 of the Protocol leaves open the opportunity to add additional activities. The Protocol does not specifically mention forest soils or forest products **but these** could be embraced by appropriate **consensus** on interpretation of the current text (see, e.g., **Schlamadinger and Marland, [5]**).

Another challenge of the Kyoto Protocol has to do with the way in which carbon credits accrue. The Protocol, and subsequent **decisions** of **the Congress** of Parties to **the Framework** Convention, establish that emissions or sinks in the biosphere will be measured as the changes in carbon stocks—exactly as illustrated in **the GORCAM** diagrams above. **Given this** dictate, the **change** in carbon stocks **for the** landowner who is host of the forest management project illustrated in Figure 2 is as shown in **Figure 3**. **The point** of comparing these **two** figures is that fossil **fuel displacement** and carbon accumulation in Forest products are real but they likely do not occur in the accounts **of** the forest manager. **The decreases** in Fossil fuel usage will always count toward compliance with Kyoto commitments, but not likely in the accounts of **the** Forest manager. Changes in carbon stocks in the **forest** will **count in the** commitments of the forest manager if they meet the requirements **of Article** 33. For projects that concentrate on the Forest carbon stocks it is hard to establish whether the harvested wood will **increase** the total **market volume**, or whether it will simply displace wood from another source. **This** distribution of credits will presumably be **captured** in the accounts of countries or large, multi-Faceted **companies** or projects; but it will be hard to capture at the level of **many** carbon dioxide mitigation projects. For **projects** that are able to **create** new demand (for example, a **woodfuel** plantation **adjacent** to a new biomass **power plant**) the **substitution** effects will occur within the bounds **of the** project, **and** will be **easier** to **account** For.

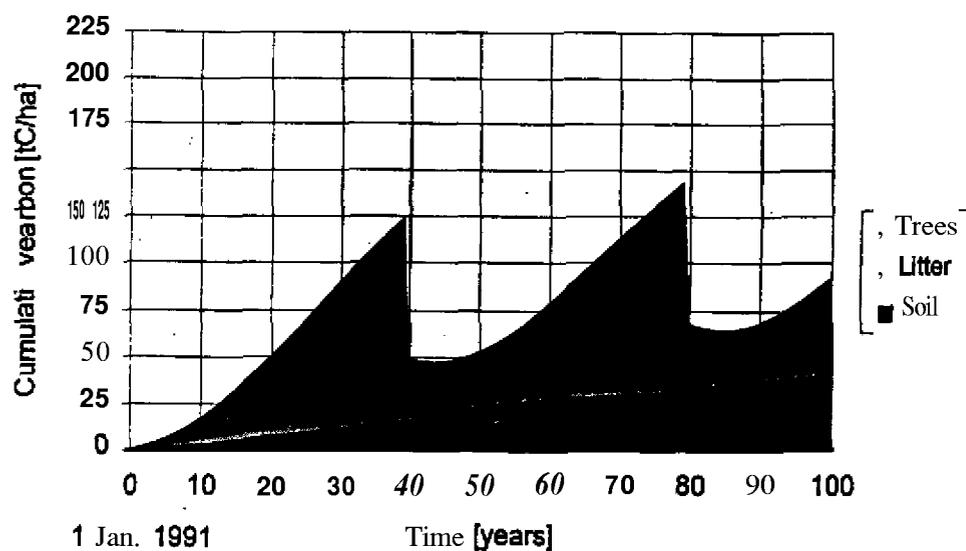


Figure 3: As in Figure 2, but only the carbon-stock changes in the account **of the land** owner are shown.

Another intriguing question raised by the Kyoto Protocol has to do **with the** magnitude of credits generated by carbon sinks. Many negotiators had considerable misgiving about including credit for carbon sinks in the Protocol and this was partly due to concern **that the** stored carbon could be measured and verified accurately. **The possibility** has been **raised** of discounting carbon sinks to accommodate the uncertainty of measurement. A proposal by Canada [6], for example, would establish that credits for sinks **require** that there be 95% **confidence** that **the** credit was indeed accomplished. **Figures 4, 5, 6, and 7** illustrate how this might **affect** carbon credits. We have taken the scenario **of Figure 2** and substituted probability distribution functions in **place** of discrete values for some of the principal parameters. **The result** is a probability distribution of potential outcomes. **This** probability distribution describes the range of possible outcomes, but can also be visualized as the result of the uncertainties in **measurement** of some parameters and hence as the uncertainty of measured outcomes.

To create **Figures 4 and 5**, we carried out 250 GORCAM model runs, with each model run using a random number generator to generate a variety of the key input parameters **defined** by probability distributions (see Note 1 for **&ails**). **Figure 4** shows **the** total net sequestration of carbon **and** this corresponds to the upper bound of **Figure 2**. **Figure 5** depicts the probability distribution for the carbon sequestration outcomes after 50 years (this is a cross section of the distribution in **Figure 4** at time 50). The 5% percentile, mean, and

95% percentile values in Figure 5 are at 99, 132, and 171 tC/ha after 50 years. In other words, in order to achieve the carbon benefits predicted in Figure 2 (128 tC) with a certainty of 95%, and with the probability distributions assumed for various input parameters, the project area would have to be increased from 1 ha to 1.29 ha (128 divided by 99). Conversely, the project envisioned in Figure 2 would generate 128 tC/ha credit if all of the values were perfectly known but only 99 tC/ha with the uncertainties assumed here and the requirement that the goal be fulfilled with 95% probability.

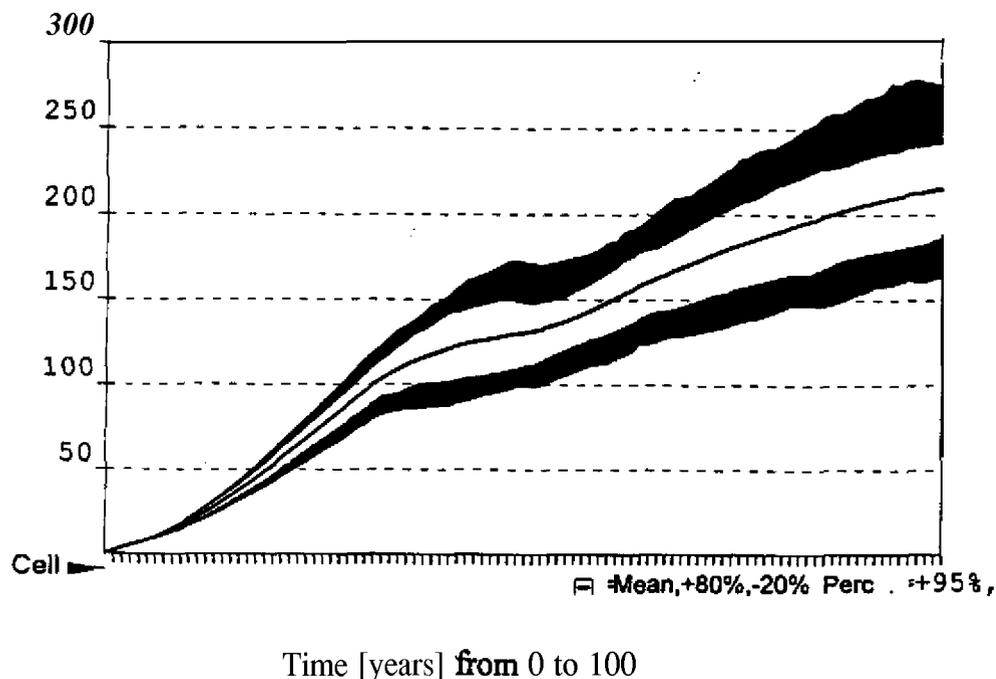


Figure 4: Cumulative carbon sequestration as in Figure 2, but with probability distributions applied to various input parameters of the GORCAM model. The line in the center of the white area represents the most likely outcome, whereas the bounds of the white area are the 20 and 80% percentiles. The outer bounds of the dark areas are the 5 and 95% percentiles.

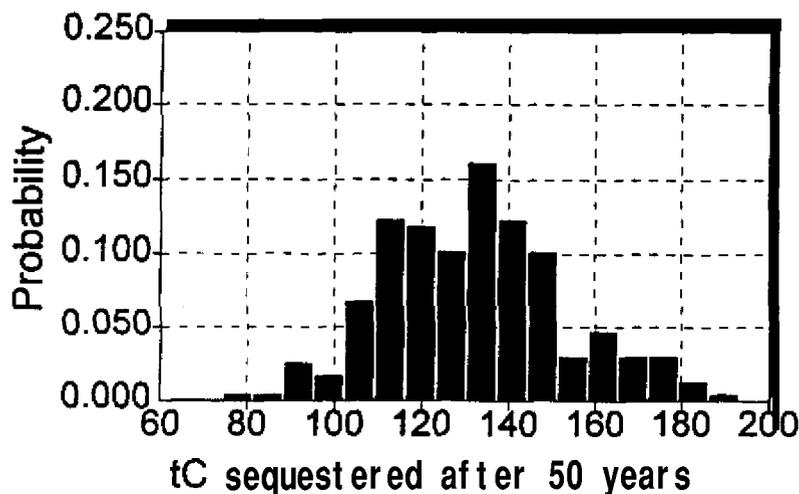


Figure 5: Cross section of the probability distribution in Figure 4, at time = 50 years

Figures 6 and 7 are exactly as in Figures 4 and 5 except that the deviations from the mean for the various input parameters are only half as large, i.e. the uncertainties of the input parameters are smaller. It can be seen that the bands for the 20/80 and 5/95 percentiles are narrower in Figure 6 than in Figure 4. A cross section of Figure 6 is provided in Figure 7. Figures 6 and 7 show that this case, with smaller uncertainty in the input parameters, will provide more credits that fulfill the 95%-certainty threshold. The 5% percentile, mean, and 95% percentile are now at 112, 128, and 145 tC/ha. The project of Figure 2 could provide credits of 112 tC/ha with 95% certainty and the probability distributions assumed in the calculations for Figures 6 and 7. In other words, the area required area to provide 128 tC of credits, which was 1 ba in the case with zero uncertainty, and 1.29 ha in the case with high uncertainty, is now at 1.13 ha with low uncertainty.

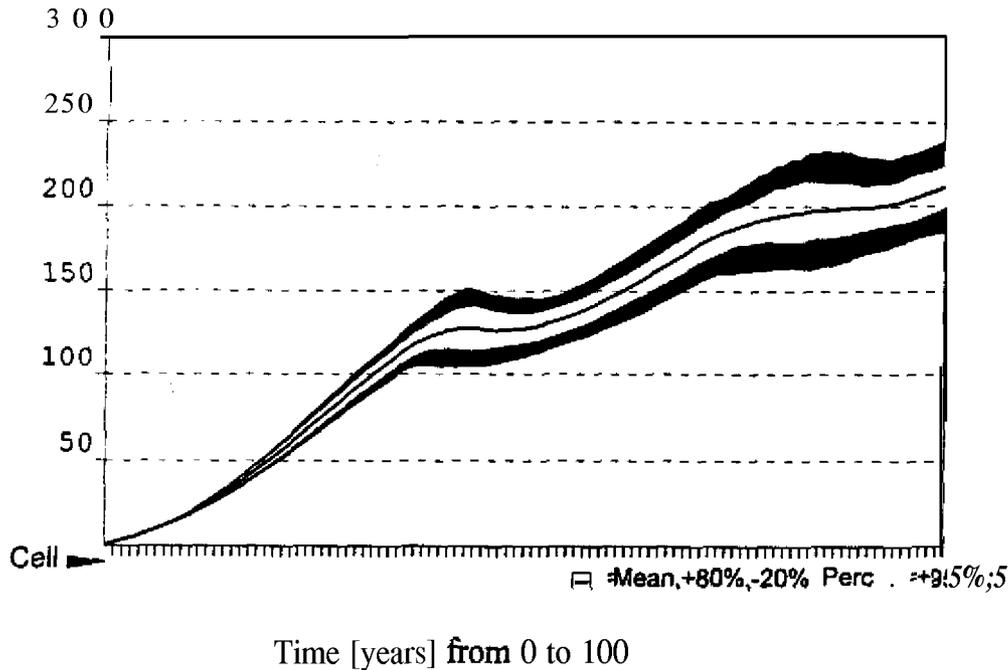


Figure 6: As in Figure 4, but with a smaller uncertainty of input parameters.

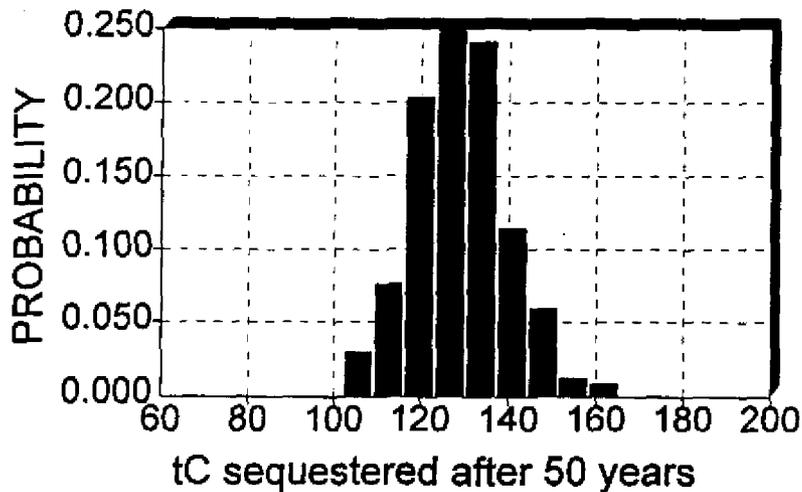


Figure 7: As in Figure 5, but with a smaller uncertainty of input parameters.

A crediting scheme that discounted credits in **proportion** to their **uncertainty** would **require careful** balancing between the need for accurate measurement of carbon **sinks** and the cost of providing the required **measurements**. **There appear** to be two ways for projects to increase carbon **credits** for a project with **uncertain** outcome. One could either **increase** the **project** area or increase the **accuracy** with which key parameters are predicted and measured.

In summary, the Kyoto Protocol establishes **the principle that removing** carbon dioxide **from** the atmosphere is to be valued in the same way **as** is reducing emissions to the **atmosphere**. At the same time it creates many challenges on how these credits are to be **measured** and credited. We have yet to **fully** agree on what activities will produce credits, what pools will be **credited**, who will **receive** credits, and how much credit will be available when there are significant **uncertainties** in measurement.

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NOTE 1:

To produce Figures 4 and 5, we started **with the scenario illustrated in** Figure 2 and simulated how the model output might respond to uncertainty in the input parameters. We assumed that the probable growth rate of trees would be distributed according to a normal distribution, with the mean given by the value used in Figure 2 and with a standard deviation of 16% of the mean. **The** harvest cycle length was **taken** to be distributed uniformly between 30 and 50 years (the discrete value in Figure 2 was 40 years). The efficiency with which fossil **fuels** are substituted (through the use of **biofuels** and through the displacement of **energy-intensive** materials with wood) was treated as a triangular distribution with the extreme **values** equal to 50 and 150% of the mean value. A triangular distribution was **also** used for the lifetime of wood products, as well as for the share of waste wood used for energy. For these later parameters the lower and upper bounds were taken to be 0 and 200% of the mean.